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For Astronomers, Big Bang Confirmation

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The most detailed and precise map yet produced of the universe just after its birth confirms the Big Bang theory in triumphant detail and opens new chapters in the early history of the cosmos, astronomers said yesterday.

It reveals the emergence of the first stars in the cosmos, only 200 million years after the Big Bang, some half a billion years earlier than theorists had thought, and gives a first tantalizing hint at the physics of the "dynamite" behind the Big Bang.

Astronomers said the map results lent impressive support to the strange picture that has emerged recently: the universe is expanding at an ever-faster rate, pushed apart by a mysterious "dark energy."

By comparing their data with other astronomical observations, the astronomers have also made far more precise calculations of the basic parameters that characterize the universe, including its age, geometry, composition and weight.

In a nutshell, the universe is 13.7 billion years old, plus or minus one percent; a recent previous estimate had a margin of error three times as much. By weight it is 4 percent atoms, 23 percent dark matter — presumably undiscovered elementary particles left over from the Big Bang — and 73 percent dark energy. And it is geometrically "flat," meaning that parallel lines will not meet over cosmic scales.

The result, the astronomers said, is a seamless and consistent history of the universe, from its first few seconds, when it was a sizzling soup of particles and energy, to the modern day and a sky beribboned with chains of pearly galaxies inhabited by at least one race of puzzled and ambitious bipeds.

The map, compiled by a satellite called the Wilkinson Microwave Anisotropy Probe, shows the slight temperature variations in a haze of radio microwaves believed to be the remains of the fires of the Big Bang. Cosmologists said the map would serve as the basis for studying the universe for the rest of the decade.

"We have laid the cornerstone of a unified coherent theory of the cosmos," said Dr. Charles L. Bennett, an astronomer at the Goddard Space Flight Center in Greenbelt, Md., who led an international team that built the satellite and analyzed the results.

The satellite was launched on June 30, 2001, and has been orbiting Earth and recording cosmic emanations from a point on the other side of the Moon. The satellite is the successor to NASA's Cosmic Background Explorer, or COBE, which first mapped the cosmic radiation in broad brushstrokes in 1992. The new satellite can resolve features one-fortieth the size of those in the COBE map.

The results were announced at a news conference at NASA headquarters in Washington yesterday and posted online at map.gsfc.nasa.gov/.

Cosmologists hailed the new map and said it had exceeded their expectations. Dr. Max Tegmark, a cosmologist at the University of Pennsylvania, called the results "wild," and said they had put the ball in the court of regular astronomy to match its precision. "MAP will be the foundation of all cosmology in the next five years," he said.

Dr. Michael Turner, a cosmologist at the University of Chicago, hailed the results as having something for everyone, confirmation of the New Cosmology that his generation had put together and "hints of surprises" for the next generation to figure out. "This is a great time to be a cosmologist," he said.

Dr. John Bahcall, an astrophysicist at the Institute for Advanced Study in Princeton, N.J., said the results were a "rite of passage" for cosmology from philosophical uncertainty to precision. "The motley mixture of strange elements that astronomers have put together over the last two or three decades is confirmed to remarkable accuracy," he said, referring to the entry of dark energy and dark matter into the astronomers' world.

Dr. David N. Spergel, a Princeton astrophysicist and member of the WMAP team, said: "We've answered the set of questions that have driven the field of cosmology for the last two decades. How many atoms in the universe? How old is the universe?"

The task now, he and others agreed, is to understand those motley elements, the dark stuff that apparently makes up 96 percent of everything, and what happened in the Big Bang that gave birth to it all.

Cosmologists do not know what dark energy is. One leading candidate is a repulsive force called the cosmological constant, which Einstein created as a fudge factor to keep the universe from collapsing in his equations, and later disavowed. But some theories of modern physics postulate mysterious force fields called quintessence as the dark energy. While the new analysis has not solved the problem, Dr. Spergel said its data seemed to favor Einstein's fudge factor.

The cosmic microwaves have mesmerized astronomers ever since they were discovered in 1965 as a faint radio hiss filling the sky by Dr. Arno Penzias and Dr. Robert Wilson, radio astronomers at Bell Laboratories who won Nobels for their work. The microwaves represent a snapshot of the universe as it was cooling to the point where atoms could form, at an age of about 380,000 years. But water vapor in the atmosphere obscures the microwaves, and so astronomers have had to be satisfied with glimpses from mountaintops or high-flying balloons.

In 1992, COBE confirmed that this cosmic gravy has lumps, the seeds from which galaxies and other cosmic structures would grow. Since then a series of smaller experiments have studied these lumps, which can be used to diagnose properties like the geometry and matter density of the cosmos, on finer and finer scales. These experiments suggested that the universe is flat and dominated by dark energy, but they only glimpsed small portions of the sky for limited times.

The new satellite scans the whole sky every six months. It is designed to operate for four years. The new map was based on the first year's worth of data.

Originally known as MAP, the satellite was renamed yesterday in honor of Dr. David Wilkinson, a Princeton cosmologist and leader of the MAP project who died last September.

In addition to measuring the brightness or temperature of the microwaves, the satellite's instruments, like a pair of

Polaroid sunglasses, can also measure the polarization of the microwaves. That ability was crucial to the discovery of the era of the first stars. Like light skipping off a lake, the electric and magnetic fields that constitute light bouncing off an electrified gas are not jumbled but show a preference to vibrate in a particular plane. Last year astronomers showed that a polarization had been imparted to the cosmic microwaves at the moment that the first atoms formed, and the cosmic fireball thus lost its free electrons.

But astronomers thought there should be another polarization episode. When the lights went on in the universe, blazing ultraviolet from the first stars would have stripped the electrons from hydrogen atoms in space. Those electrons, which scatter the cosmic microwaves, would also polarize them again.

Most astronomers suspected that this had happened at about the time of the most distant and early quasars, around 800 million years of age. It was a surprise, astronomers said, to find the stars had formed so early.

The first stars, Dr. Bennett explained in an interview, were probably monsters 100 times as massive as the Sun and burned out rapidly and violently, transmuting primordial hydrogen and helium into heavy elements like carbon and oxygen and spewing them out into space to form the basis for future generations of stars and eventually life.

The scientists also said that their data was beginning to shed light on a theory of what might have been going on during the Big Bang.

That theory, known as inflation, hypothesizes that the universe underwent an enormous growth spurt during the first trillionth of a trillionth of a second of time under the influence of a brief but powerful antigravitational field that permeated space. Such behavior is allowed by the laws of physics, and it has formed the core of Big Bang theorizing, but the details depend on the unknown physics that prevails at the energies of the early universe — far beyond the capacity of modern particle accelerators. And so inflation, as Dr. Bennett noted, is often called a paradigm instead of a theory.

By analyzing the bumps in the cosmic microwaves, which according to inflation are the result of microscopic fluctuations in the mysterious force field that drove inflation, along with other data, Dr. Spergel said, the scientists have ruled out one simple version of inflation that is often seen in textbooks. Other versions, he added, fit the data quite well.

"The data are good enough to rule out whole classes of inflationary theories," Dr. Spergel said. That is a boon, he said, for particle physicists, who want to know what laws governed the universe at the beginning of time.

"It really is a big hint for them," he said.

Dr. Andrei Linde, a cosmologist at Stanford and one of the fathers of inflation theory, and the inventor of the model that was ruled out, said that it was "great" that theories were getting culled.

He said that it was "painful" for him that one of his theories got killed, but that it was good news that several of his other versions were doing well.

Dr. Turner said: "This is the door to precision cosmology being opened. It's the first step in a long march."